COMPARATIVE STUDIES OF MECHANICAL AND THERMAL PROPERTIES OF BISMUTH-CADMIUM (Bi-Cd), BISMUTH-LEAD (Bi-Pb) AND LEAD-CADMIUM (Pb-Cd) BINARY ALLOYS GROWN BY ZONE - REFINING TECHNIQUE

Crystals are the pillars of world of modern technology. Without crystals, there would be no electronic industry, no photonic industry, no fibre optic communications, those depends on materials or crystals such as semiconductors, superconductors, polarizer, transducers, radiation detectors, ultrasonic amplifiers, ferrites, magnetic garnets, solid state lasers, non-linear optics, piezo-electric, electro-optic, acousto-optic, photosensitive, refractory of different grades, crystalline films for microelectronics and computer industries. In the past few decades, there has been a growing interest on crystal growth processes, particularly in view of the increasing demand of materials for technological applications.[1-2]

Modern technologies based on optoelectronics, acousto-optics has exploited the versatile properties of crystals. The rapid advances in these branches of technologies have been made possible due to the availability of a variety of crystalline materials. In other words the development of the crystalline materials is the backbone of the modern technologies. Within the past few years, single crystals have became extremely important in many of our modern technologies, in particular electronic microcircuits, which employ single crystals of silicon and other semiconductors.

Growth of crystal ranges from a small inexpensive technique to a complex sophisticated process and crystallization time ranges from minutes, hours and days to months. It is a highly complex phase change phenomenon. It represents a controlled change of state, or phase change, to the solid (condensed) state. It is the process of the birth and development of a solid phase with a regular structure out of a disordered and irregular state, and thus it can be regarded as a first-order phase transition.

An alloy is a substance that has metallic properties and is composed of two or more chemical elements, of which at least one is metal. Alloy may be classified according to

their structure, and complete alloy system may be classified according to the type of their equilibrium or phase diagram. Alloys are normally harder than their components, less ductile and have a much lower conductivity, whereas the highly purified single crystal of a metal is very soft and malleable, with high electrical conductivity. Eutectic alloys have low melting points, excellent fluidity, and good mechanical and electrical properties. Consequently, a broad spectrum of eutectic alloys that are available for different applications have been developed.[3-5]

When Bismuth is alloyed with other metals such as lead, tin or cadmium, it forms low-melting alloys, which are extensively used for safety devices in fire detection and extinguishing systems.[6-7] Bismuth rich alloys (>50 wt %) have the unique feature that they expand on solidification.[8] Pure Lead is soft. Alloying constituents are added to pure lead to harden the metal, strengthen it, lower its melting point, or otherwise extend its range of useful application. Cadmium is resistance to corrosion and as a result it is used as a protective layer when deposited on other metals. Small amount of Cadmium can improve the hardness, wear resistance, mechanical strength, fatigue strength, castability and electrochemical properties of number of alloys.

Bismuth-Cadmium (Bi-Cd) is a prototype of a quasi-regular eutectic alloy in which the bismuth- rich phase has a volume fraction of 57%. Liquid metal such as Bi and Pb and Lead-Bismuth (Pb-Bi) eutectic alloy are serious contenders for use as coolant in the liquid metal-cooled fast breeder nuclear reactors (LMFBRs) in lieu of sodium due to a number of attractive characteristics (high density, low moderation, low neutron absorption and activation, high boiling point and poor interaction with water and air.)[9,10] Lead-Bismuth eutectic is known to expand after solidification over time, up to about 1% volumetric.[11] Cadmium-Lead (Cd-Pb) is a prototype of a regular eutectic alloy.[12] These alloys were grown by Zone Refining Technique.

The properties of alloys may vary according to phase diagrams. The alloys containing finer grains are hard and have high yield strength and ultimate strength. Their thermal and electric conductivities are low. An alloy containing coarse grains or large grains has low hardness, yield strength, ultimate strength and high values of thermal and electrical conductivities.

For the characterization and the analysis of the grown binary alloys, adequate understanding of the experimental procedures and instrumentation is necessary. For recording the observations taken during the present investigation, different experimental techniques like Zone Refining Set Up, Energy Dispersive Analysis by X-Ray (EDAX), Micro-Hardness, Thermo Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) have been utilized.

In this thesis, comparative studies of mechanical and thermal properties are done for Bismuth-Cadmium, Bismuth-Lead and Lead-Cadmium alloys. All the results are carried out for different temperature and for different loading time with variation of load. This thesis contains 6 chapters.

Chapter 1: It gives the general information of the Crystal Growth Techniques.

Chapter 2: Explains phase diagram in detail with the explanation of time-temperature cooling curve, interpretation of phase diagram, classification of phase diagram, phase diagram and properties of alloys, phase diagram for allotropic metals and Hume - Rothery's Rules. It also describes the phase diagram of Bismuth-Cadmium, Bismuth-Lead and Lead-Cadmium alloys.

Chapter 3: Explains types of zone melting process, the theory of Zone Refining Technique. Bi-Cd, Bi-Pb and Pb-Cd alloys were grown by Zone Refining Technique. This chapter also explains importance of Bismuth, Lead, Cadmium and application of Bi-Cd, Bi-Pb and Pb-Cd alloys and qualitative analysis of EDAX for confirmation of composition in said binary alloys.

Chapter 4: Explains the theory of hardness. Hardness is a measure of the resistance of the material to permanent deformation or damage. Its value depends not only on the properties of the indented material but also to an extent on the shape of the indenter, the rate of load application, and the friction between the indenter and the material.[13] Indentation tests represent a practical methodology for material characterization since not only hardness, but also material and surface properties such as elastic modulus, yield strength, and scratch resistance can be referred from the indentation curves.

In the present work after growing alloys, the effect of different loading time on hardness at different indentation load and the effect of temperature on hardness with constant loading time are studied and graph of Load vs. Hardness is plotted. From hardness, other

mechanical parameters like Elastic Modulus (E), Yield Strength (Y), Ultimate Tensile Strength (T) and Stiffness (S) have been calculated.

The work hardening co-efficient (n) of the material is related to the load (P) by the relation $P = ad^n$, Where "a" is an arbitrary constant, and d = length of diagonal. The plot of log P vs. log d is plotted for grown alloys at room temperature and for different temperature. Hence, work-hardening co-efficient are calculated[14]. Also, Activation Energy (E) and Softening Coefficient (B′) are calculated.

Chapter 5: Explains Thermal behavior of grown alloys. The studies of thermal behavior, practically as well as scientifically not explains the behavior of crystals expressed high temperature but also assist in establishing the criteria for selection of material for specific uses.[15]

In the present work, the method of Broido has been employed for estimation of energy of activation for thermal degradation. Thermo Gravimetric Analysis **(**TGA**)** graphs are taken in a definite temperature range (28°C - 600°C). Frequency Factor (A), Change in Entropy (ΔS), Change in Enthalpy (ΔH) and Gibb's Free Energy (ΔG) are also calculated from thermogram. Result from Differential Scanning Calorimetry (DSC) thermograms are shown in this chapter.

Chapter 6: Contains the overall discussion of results and conclusions derived. Attempts have been made to correlate the results of the present study and also discuss the scope of further work for Bi-Cd, Bi-Pb and Pb-Cd alloys.

REFERANCES

1. Nalwa H. S. and Miyata S., 'Nonlinear optics of organic molecules and polymers', CRC Press, Boca Raton, FL, (1997).
2. Brice J. C., 'Crystal Growth Processes', Halsted Press, John Wiley and Sons, New York, (1986).
3. E. Cadirh, H. Kaya, A. Gumus and I. Yilmazer, Journal of Materials Engineering and Performance, Volume 15(4), p 490-493, August (2006).
4. R. Elliott, Eutectic Solidification Processing, Butterworths, London, p. 60-91, (1983).
5. M. C. Flemings, Solidification Processing, McGraw-Hill, New York, p. 67-103, (1974).
6. Rizk Mostafa Shalaby, J. Mater. Sci. Technol., Vol. 25 No. 4, (2009).
7. M. Kamal, M. Mazen, A. B. El-Bediwi and E. Kashita: Radiant. Eff. Defetts Solids, 160(8), p. 369, (2005).
8. Mustafa Kamal, Maher El-Tonsy, Eman Kashita, Phys. Stat. sol. (a) 201, No.9, p. 2029-2034 (2004).
9. Abdul-Majeed Azad, Journal of Nuclear Materials 341, p.45-52, (2005).
10. B. B. Alchagirov, A. M. Chochaeva, A. G. Mozgovoi, M. N. Arnol'dov, V. B. Bekulov, Kh. B. Khokonov, High Temperature, Vol. 41, No. 6, pp. 755-761, (2003), Translated from Teplofizika Vysokikh Temperatur, Vol. 41, No. 6, pp. 852-859, (2003).
11. F. Groeschel, J. Patorski, Spallation Neutron Source (ASQ), Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland.
12. I. H. Moon, Y. L. Kim, I. S. Ahn, Journal of Materials Science 16, p.1367-1373, (1981).
13. A. P. Semenov, Russian Engineerning Research, Vol. 28, No.12, pp.1177-1182, (2008).
14. A. Pricilla Jeyakumari, J. Ramajothi, and S. Dhanuskodi,:Jr. Cryst. Growth, 269,p. 558, (2004)
15. Amina Jain,Susma Bhat, Sanjay Pandit, M.L.Koul and P.N.Kotru, : Bull.Mater.Sci.,20 p. 1089, (1997).

LIST OF PUBLICATION AND PRESENTATION

1. **Comparative studies of Micro-Hardness of Bismuth-Cadmium (Bi-Cd) and Bismuth-Lead (Bi-Pb) Alloys Grown By Zone - Refining Technique;** International Conference on Materials for Advanced Technologies (ICMAT) Conference Proceeding; EE-PO4; p.14; **(2011)** National University of Singapore, Singapore.
2. **Study of Micro Hardness of Lead-cadmium (Pb-Cd) Binary Alloys Grown by Zone - Refining Technique;** International Conference of Young Researchers on Advanced Materials (ICYRAM) July 1-6, **(2012)**, Singapore. (Accepted for presentation)
3. **Comparative studies of mechanical properties of Bismuth-Cadmium (Bi-Cd), Bismuth-Lead (Bi-Pb) and Lead- Cadmium (Pb-Cd) Binary Alloys Grown By Zone - Refining Technique**; Bulletin of Pure and Applied Sciences, ISSN-0970-6569, **(2012)**. (Send for publication)

Signature of Supervising Teacher Signature of Candidate

[I. B. PATEL] **[ARTI H. PRAJAPATI]**